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Low frequency noise

Birgitta Berglund, lead editor of the WHO *Guidelines for Community Noise*,[180] stated in a review of low frequency noise effects:

> Although the effects of lower intensities of low-frequency noise are difficult to establish for methodological reasons, evidence suggests that a number of adverse effects of noise in general arise from exposure to low frequency noise: Loudness judgments and annoyance reactions are sometimes reported to be greater for low-frequency noise than other noises for equal sound-pressure level; annoyance is exacerbated by rattle or vibration induced by low-frequency noise; speech intelligibility may be reduced more by low-frequency noise than other noises except those in the frequency range of speech itself, because of the upward spread of masking.
>
> Low-frequency noise (infrasound included) is the superpower of the frequency range: It is attenuated less by walls and other structures; it can rattle walls and objects; it masks higher frequencies more than it is masked by them; it crosses great distances with little energy loss due to atmospheric and ground attenuation; ear protection devices are much less effective against it; it is able to produce resonance in the human body; and it causes greater subjective reactions (in the laboratory and in the community studies) and to some extent physiological reactions in humans than mid- and high frequencies.[181]

[180] World Health Organization. 1999. *Guidelines for Community Noise*, ed. Berglund B, Lindvall T, Schwela DH. 159 pp. www.who.int/docstore/peh/noise/guidelines2.html

[181] Berglund B, Hassmen P, Job RFS. 1996. Sources and effects of low frequency noise. J Acoust Soc Am 99(5): 2985–3002, p. 2985.

> Low-frequency noise also differs from other noise in producing vibrations of the human body and other objects. . . . Motion sickness has been linked to low-frequency noise even without accompanying vibration.[182]

Many subjects in the present study stated that turbine noise was different from other types of noise, using words like "invasive" and "unnatural," and saying that it was impossible to get used to this noise. Several said it wouldn't sound loud to people who did not live at their homes, or they described a "swish" or "hum" as extremely bothersome noises. A number spoke favorably of living near heavily traveled roads or urban train lines, compared to living near wind turbines. All who moved, moved into villages, towns, or suburbs, where there was more traffic but no danger of turbines being built next to them. The descriptions make it clear that there is a disturbing quality about turbine noise which is more than its audible loudness and that, over time, people become sensitized to wind turbine noise, rather than get used to it.

In the present study, Mr. and Mrs. G described a resonance or standing wave phenomenon in one room of their turbine-exposed home. At one end of this room, Mrs. G felt internal vibration, even though she could not feel any surfaces or objects vibrating when she put her hand on them. Mr. G felt peculiar in the same place, and always had to walk quickly away from that spot before his feeling progressed to nausea. In the home of family C, an audiologist detected vibration in the floor of a small room the family identified as having the worst problem in the home, and felt nauseated when he put his forehead against it.[183]

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182 Berglund et al. 1996, p. 2993.

183 Personal communication from acoustician; name withheld for confidentiality reasons.

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At a NASA test facility in the 1960's, healthy young men were exposed to low frequency noise in the 1–50 Hz frequency range at 110 to 150 dB for 2–3 minutes (high amplitude and short duration). Over the full 1–50 Hz frequency range they experienced fatigue and took longer to perform assigned tasks. At frequencies less than 25 Hz there was an "annoying tickling" in the ear. In the same frequency range, there were modulations of speech, moderate vibrations of the chest, and fullness in the hypopharynx with an annoying gag sensation. "In regard to the opinions of those tested, it was indicated that the sensations involved were impressive."[184]

A case that was similar to the cases presented in this paper involved a couple in Germany in 1996. After moving into a new house outside a provincial city, the couple experienced symptoms with increasing intensity, including "indisposition, decrease in performance, sleep disturbance, headache, ear pressure, crawl parasthesy,[185] or shortness of breath."[186] Their case was intensely investigated with both A-weighted and linear measurements of noise indoors and outdoors, correlated in real time with the couple's symptoms. In time, the symptoms were correlated with intensity of noise below 10 Hz. The couple's symptoms and the intensity of noise below 10 Hz both varied with the wind and weather, and were worse in the winter. No plausible mechanism for production of such noises or correspondences to local sources of noise, such as the housing complex heating plant, was found. Symptoms occurred when the sound pressure level at 1 Hz was 65 dB, well

[184] Edge PM, Mayes WH. 1966. Description of Langley low-frequency noise facility and study of human response to noise frequencies below 50 cps. NASA Technical Note, NASA TN D-3204. 11 pp.

[185] *Paresthesia* means a prickling sensation, the "pins and needles," felt when a numb foot is waking up. I interpret "crawl parasthesy" to mean a sensation like insects crawling on the skin or in the chest. One of the current study's subjects, I2, also described "pins and needles" inside her chest.

[186] Feldmann J, Pitten FA. 2004. Effects of low-frequency noise on man: a case study. Noise Health 7(25): 23–28.

below hearing threshold. None of the frequencies responsible for the symptoms, all below 10 Hz, had sound pressure levels above 80 dB. The decibel levels that affected the man and wife in their home were far less than their own threshold hearing levels measured in a sound lab. The authors hypothesized that infrasound, with its very long wavelengths (10 Hz, for example, has a 34 m wavelength in air), causes strong pressure fluctuations in relatively small closed rooms—pressure fluctuations that are detected more by the whole body and its inner organs than by the ears.

Similar intensive investigations, using linear as well as A-weighted sound levels, 1/3 octave sound pressure levels down to 1 Hz, indoor measurements, and assessments of wall vibration, have proved fruitful in other low frequency noise complaint investigations.[187] These investigators, from a state environmental agency in Germany, paid attention to spontaneous statements by the affected people, to see whether perceptions of noise followed a systematic pattern. They found that "noises which in many cases induced vehement complaints were to a large extent of rather low sound levels,"[188] and that indoor ventilator noise and noises generated by structure-borne sound transmission were distinctly more disturbing than road traffic noise. These authors documented standing waves in rooms by measuring and comparing loudness in dBA and dB(lin) at the center of the room and near walls. They detected vibration in walls, and correlated the dominant frequency and its corresponding wavelength to the size of the room in discussing how a standing wave was established in the room.

For this kind of complaint, the authors noted,

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[187] Findeis H, Peters E. 2004. Disturbing effects of low-frequency sound immissions and vibrations in residential buildings. Noise Health 6(23): 29–35.

[188] Findeis and Peters 2004, p. 29.

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> More than half . . . were made on the grounds of sleep disturbance. Quite often symptoms like "a roaring in the head, especially when lying down" were brought forward. Time and again, "a feeling of riding a lift [elevator]" was reported, and over and again the measuring team had the impression that the reported immissions [noise] meant a nerve-wracking experience for the exposed persons. Several complainants even got into a state of being aggressive. There were reports by a number of trustworthy persons on how they at first—for instance when moving into the flat—did not even notice any immissions. But in the course of a few weeks they began to perceive them distinctly and [the immissions] became intolerable after continued exposure. It was obvious that in these cases the sensibility of specific noise components had developed. Thus, it is understandable that non-exposed persons were at a difficulty to even acknowledge such noise immissions.[189]

Wind turbines produce noise in the low and infrasonic frequency ranges. The issue has not been whether they produce low frequency or infrasonic noise, but whether the amplitudes are sufficient to cause human effects. According to data published by van den Berg,[190] unweighted amplitudes at 1 Hz, at one wind park under one set of weather conditions, were in the 70–100 dB range, declining to the 55–75 dB range at 10 Hz and the 50–60 dB range at 100 Hz. Wind turbine noise has a pulsating quality, produced as the airfoil blades swing past the tower, compressing the air between blade and tower. These low frequency pressure fluctuations, among other effects, modify the loudness of the higher frequency sounds coming from the turbines, producing the audible "swish"

[189] Findeis and Peters 2004, p. 32.

[190] van den Berg 2004a.

that synchronizes with the feeling of pulsation some subjects felt in their chests. Coming from several towers at once, these low frequency air pressure fluctuations may synchronize and reinforce, depending on the orientation of the towers and house and the timing of the individual turbines. Three families in this study (A, B, and F) lived in houses nearly in line with a row of turbines. For families A and B, the area's worst storms, "nor'easters," swept right down the line towards their houses, which were built on a hill at the level of the turbine hubs. These two families, though they were a kilometer (about 3300 feet) from the closest of the 10 turbines, moved out faster—in five months—than any of the other families, and had particularly severe symptoms.

Studies of turbine noise also show that noise carries farther than predicted by conventional industry modeling. This has to do not only with the low frequency components of the noise, which attenuate less with distance, but also with layering of the atmosphere at night, which creates cool still air at ground level and brisk, laminar airflow at turbine hub heights.[191] Industry models do not take these factors into account. Nor do they allow for a noise source more than 30 m above the ground. (Turbine hub heights in this study were 59–90 m.) Nor do they allow for increased transmission of sound in front of and behind the blades (with less sound transmission in the plane of the blades, including under the turbines), sky reflections, or weather conditions that focus the noise transmissions.[192]

Vibroacoustic Disease (VAD) model

High intensities of low frequency noise over prolonged time periods may cause marked neurologic damage, as described

[191] van den Berg 2004b.

[192] Richard James, INCE Full Member, personal communication, 5/11/08.

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by the Vibroacoustic Disease (VAD) group in Portugal.[193] This is a provocative body of research, full of interesting case descriptions and pathology studies, but compromised by absence of specified study group criteria, absence of control groups, and lack of quantification. The study group consists of 140 aircraft maintenance and repair technicians in the Portuguese Air Force, of whom 22 (15.7%) had adult-onset epilepsy, compared to a national prevalence of 0.2%.[194] Some of the case descriptions of the subjects with epilepsy also include cognitive decline, depression, paranoia, and rage attacks.[195] The descriptions are similar to those of retired professional football players with histories of multiple concussions.[196,197] The vibroacoustic disease researchers ascribe VAD pathology to whole-body vibration induced by the noise, with the pathology of each body part induced by vibration of that part. Neurologic effects may be due to neuronal or axonal shearing, as in the multiple concussions scenario, or due to microangiopathy in the brain, meaning, effects on and occlusion of small blood vessels.[198]

With regard to the chest, the VAD researchers have used human autopsy and biopsy and animal rearing studies to describe loss of

[193] Castelo Branco and Alves-Pereira 2004.

[194] Castelo Branco and Alves-Pereira 2004.

[195] Martinho Pimenta AJ, Castelo Branco NAA. 1999. Neurological aspects of vibroacoustic disease. Aviat Space Environ Med 70(3): A91–95.

[196] Omalu BI, DeKosky ST, Minster RL, Kamboh MI, Hamilton RL, Wecht CH. 2005. Chronic traumatic encephalopathy in a National Football League player. Neurosurgery 57: 128–34.

[197] Omalu BI, DeKosky ST, Hamilton RL, Minster RL, Kamboh MI, Shakir AM, Wecht CH. 2006. Chronic traumatic encephalopathy in a National Football League player: part II. Neurosurgery 59: 1086–93.

[198] Martinho Pimenta and Castelo Branco 1999.

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cilia and microvilli from epithelial surfaces of the bronchi,[199–201] pleura,[202] and pericardium.[203] They also describe thickening of bronchial epithelial basement membrane,[204] pericardium,[205] and blood vessel walls[206] by extra, organized collagen and elastin. Several of the animal-rearing studies on bronchial epithelial changes are well controlled and convincing.[207,208]

Based on the vibroacoustic disease research, I hypothesize that vibratory or pulsating air pressure fluctuations in subjects' airways in the present study may induce shearing of surface cilia, thus impairing the clearance of mucus and particulates from airways. This in turn could make subjects more susceptible to lower respiratory infections and increased airway irritation and reactivity (asthma). The Eustachian tube and middle ear could be susceptible

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199 Oliveira MJR, Pereira AS, Ferreira PG, Guinaraes L, Freitas D, Carvalho APO, Grande NR, Aguas AP. 2004. Arrest in ciliated cell expansion on the bronchial lining of adult rats caused by chronic exposure to industrial noise. Environ Res 97: 282–86.

200 Oliveira MJR, Pereira AS, Castelo Branco NAA, Grande NR, Aguas AP. 2002. In utero and postnatal exposure of Wistar rats to low frequency/high intensity noise depletes the tracheal epithelium of ciliated cells. Lung 179: 225–32.

201 Monteiro M, Ferreira JR, Alves-Pereira M, Castelo Branco NAA. 2007. Bronchoscopy in vibroacoustic disease I: "pink lesions." Inter-Noise 2007, August 28–31, Istanbul, Turkey.

202 Pereira AS, Grande NR, Monteiro E, Castelo Branco MSN, Castelo Branco NAA. 1999. Morphofunctional study of rat pleural mesothelial cells exposed to low frequency noise. Aviat Space Environ Med 70(3): A78–85.

203 Castelo Branco NAA, Aguas AP, Pereira AS, Monteiro E, Fragata JIG, Tavares F, Grande NR. 1999. The human pericardium in vibroacoustic disease. Aviat Space Environ Med 70(3): A54–62.

204 Castelo Branco NAA, Monteiro M, Ferreira JR, Monteiro E, Alves-Pereira M. 2007. Bronchoscopy in vibroacoustic disease III: electron microscopy. Inter-Noise 2007, August 28–31, Istanbul, Turkey.

205 Castelo Branco et al. 1999.

206 Castelo Branco NAA. 1999. A unique case of vibroacoustic disease: a tribute to an extraordinary patient. Aviat Space Environ Med 70(3): A27–31.

207 Oliveira et al. 2004.

208 Oliveira et al. 2002.

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to the same process, leading to prolonged middle ear effusions and unusual acute infections.

The increased asthma seen in subjects F1 and F3 may also have a connection to their frequent use of paracetemol (acetaminophen) for headaches during turbine exposure.[209]

Community noise studies and *annoyance*

Studies of community noise frequently assess a quality called *annoyance*. "Apart from 'annoyance,'" the World Health Organization writes, "people may feel a variety of negative emotions when exposed to community noise, and may report anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, or exhaustion."[210]

Beyond even these negative emotions, moving out of an owned home indicates that people feel sick and under threat, judging that their survival and well-being, and that of their children, will be enhanced by moving out—even as they exhaust limited resources to do so and face unrecompensed loss of their major asset, their home.

Sick and *annoyed* are not the same thing. In English, *annoyance* carries an air of triviality, like a mosquito buzzing around one's head. *Sickness* threatens survival itself.

Pedersen and Persson Waye assessed annoyance (which may be a shorthand for the above list of negative emotions, but remains different from sickness) among 351 households near wind turbines in Sweden in 2000. They used a mailed survey and compared annoyance to modeled A-weighted sound pressure levels they

[209] Beasley et al. 2008.

[210] World Health Organization 1999, *Guidelines for Community Noise*, p. 50.

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calculated to exist outside homes near clusters of one to five turbines of power 0.15–0.65 MW (much smaller than in the current study), based on the homes' distances from turbines.[211] They found people to be highly annoyed by wind turbine noise at sound pressure levels much lower than for other types of community noise. The A-weighted decibel level (in a measure averaged and weighted over time, L_{eq}) that corresponded to 15% of the people being highly annoyed was 38 dBA for wind turbines, 57 dBA for aircraft, 63 dBA for road traffic, and 70 dBA for railways. The curve for annoyance due to wind turbine noise had a steep slope, so that by 41 dBA, 35% of people were *highly annoyed*. Sixteen percent of respondents over 35 dBA reported that their sleep was disturbed by wind turbine noise.

I interpret this result as an indication of the degree to which wind turbine noise has a disturbing quality not captured by its A-weighted measurement. Since A-weighting emphasizes higher frequencies and filters out lower frequencies, the qualitative difference may be related to the presence of low frequency components. Even without directly measuring the low frequency components, this study is potentially useful with regard to regulating noise and determining setback distances for turbines. Since the study was done in units of dBA outside houses, and most community noise regulations (including for wind turbines) also use units of dBA outside houses, we can easily translate this result into the recommendation that wind turbine ordinances need to limit the turbine noise levels outside houses to less than 35 dBA. This does not mean that only 35 dB of real noise is present, but rather that in the common measurement unit of community noise—which is dBA—35 is a number that represents a significant amount

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211 Pedersen E, Persson Waye K. 2004. Perception and annoyance due to wind turbine noise: a dose-response relationship. J Acoust Soc Am 116(6): 3460–70.

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of sleep disturbance and high annoyance if the noise comes from wind turbines.

In a continuation study that involved interviewing participants, Pedersen found that some people had moved out of their homes, rebuilt their homes in an attempt to exclude turbine noise, or begun legal proceedings because of problems associated with turbine exposure.[212] Pedersen and Persson Waye also found informants who were sensitive to both noise and blade motion, felt violated or invaded by turbine noise, and found their houses to be places where they could no longer find restoration[213]—qualitative similarities to the current study.

Van den Berg, Pedersen, and colleagues conducted another survey study of noise and annoyance in the Netherlands in 2007.[214] They mailed questionnaires to 1960 households within 2.1 km (1.3 mi) of at least two adjacent 0.5–3 MW turbines, with 725 responses (37% response rate). The questionnaire asked about visual and auditory perceptions, economic benefit, annoyance, chronic diseases, current symptoms, psychological stress, and sleep disturbance, and looked at variation in these factors (as in the Swedish study) against modeled A-weighted noise levels.

Though it contained several questions about health, this study was not properly constructed to sample health in an accurate or realistic way. The evidence for this is found in the study results themselves, which contain significant bias or skew relative to known health parameters.

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[212] Pedersen 2007.

[213] Pedersen and Persson Waye 2007.

[214] van den Berg et al. 2008b.

For example, 2% of respondents in this study indicated that they had chronic migraine disorder.[215] The population prevalence of migraine disorder is remarkably stable across countries and time when controlled for age, sex, and definition of the disease, being 5–6% for males and 15–18% for females.[216,217] A finding of 2% is an underestimate, indicating that something about this study's method of sampling migraine prevalence was awry.

Sampling and sampling error occur at several levels, such as the level of selecting respondents and the level of sampling the respondents' thoughts through questioning. Potential flaws at each level can be identified in this study.

First, the researchers attempted to elicit objective health information with just two questions in this survey, one on past or underlying health and one on current symptoms. (Separate questions addressed sleep disturbance.) This is the single question about underlying health:

> 37. Do you have any long term/chronic disease? (no → 38, yes). *If yes, which chronic disease do you have?* (diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, migraine, other *viz:*)[218]

This is a very brief and superficial question, and it is not surprising that it failed to capture all the diagnoses of migraine that should have been present in a random population sample. In medical

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[215] van den Berg et al. 2008b, p. 48.

[216] Lipton RB, Bigal ME, Diamond M, Freitag F, Reed ML, Stewart WF; AMPP Advisory Group. 2007. Migraine prevalence, disease burden, and the need for preventive therapy. Neurology 68(5): 343–49.

[217] Stewart WF, Simon D, Shechter A, Lipton RB. 1995. Population variation in migraine prevalence: a meta-analysis. J Clin Epidemiol 48(2): 269–80.

[218] van den Berg et al. 2008b, Appendix p. 5.

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research, in contrast, the presence or absence of a diagnosis in a subject is established by multiple proven and validated questions directly tied to the formal definition of the illness, administered by a trained interviewer. Even in clinical practice, which is less formal, an accurate review of systems still requires a series of specific screening questions and the knowledge of when and how to question in further depth. No clinician or health researcher would rely on a question like the above to elicit full and accurate information about the past health history.

The same question also failed to elicit accurate prevalence figures for tinnitus. Tinnitus prevalence among survey respondents was 2%, whereas 4% is the likely population-level figure for the respondents' average age of 54.[219] Tinnitus prevalence also did not show age differences in this sample,[220] whereas in reality tinnitus has a well-documented pattern of increasing prevalence with advancing age.[221]

The question's time frame is also unclear. Were the authors trying to find out about baseline susceptibilities (health conditions before turbines) or did they hypothesize that exposure to wind turbines might alter the prevalence of these chronic conditions? Though they never state it explicitly, their analysis makes it clear they hypothesized that health effects due to wind turbines, if they exist, would present as higher levels of the listed chronic diseases closer to wind turbines.[222] To think that they might find such an effect with this type of sample size and mode of study verges on silly, it is

[219] National Institute on Deafness and Other Communication Disorders, USA, website, "Prevalence of chronic tinnitus." 2009. www.nidcd.nih.gov/health/statistics/prevalence.htm

[220] van den Berg et al. 2008b, p. 47.

[221] National Institute on Deafness and Other Communication Disorders, "Prevalence of chronic tinnitus." 2009.

[222] van den Berg et al. 2008b, p. 50.

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so far outside the parameters of how such issues are studied (see, for example, studies cited in footnotes 171–177, above). As a result, this study's failure to find such an effect is meaningless.

There were also sampling problems at the level of subject selection. First, the study has no control population that is not exposed to turbine noise. It samples within 2.1 km (1.3 mi) of turbines, using the unspoken assumption that the people at the outer edge of this radius will not be exposed to significant amounts of turbine noise and can therefore act as a control group. An epidemiologic study, in contrast, would have a control group of households subjected to all the same procedures for household selection, questioning, and noise modeling as the study group, but without turbines present.

Second, uncontrolled subject selection processes occurred at the level of the household. Once questionnaires reached households, what happened? Nearly two-thirds of households declined to respond. The researchers studied a subset of non-responders using a very brief questionnaire that yielded a modestly higher (48%) response rate. The brief questionnaire showed that non-responders were similar to responders in their average degree of annoyance at wind turbine noise, but did not address the issue of whether non-responders differed from responders in health parameters.

An additional process of self-selection occurred within responder households, since only one individual replied and only answered questions about himself. The householders chose who replied. On a very mundane and human level, we can imagine how this process might have selected against migraineurs in the sample, if the person with a headache the day the survey arrived asked someone else to fill it out.

The survey's second question about health concerned current symptoms, as follows:

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38. Have you been troubled by the following symptoms during the last months? ((almost) never, at least once a month, at least once a week, (almost) daily) [sic]

Headache
Undue tiredness
Pain and stiffness in the back, neck or shoulders
Feeling tense or stressed
Depressivity
Not very sociable, wanting to be alone
Irritable
Resigned
Fearful
Concentration problems
Nausea
Vertigo
Mood changes
Other, namely: *(please indicate what)*[223]

This is an odd list of "symptoms"—an undifferentiated mix of physical and psychological, with a few simple "feeling words" thrown in. It does not make sense as a symptom list—not without more detail and structuring into symptom groups. As with the chronic disease question, above, medical researchers and clinicians know that accurate and complete information cannot be elicited in this format, especially about delicate subjects like mood states and health. This question, too, is unclear about timing—pre-existing vs. during exposure, while near turbines or away from them.

This question in fact yielded little information that was useful to the researchers. In their analysis, the only reference to the health symptoms question is as follows:

[223] van den Berg et al. 2008b, Appendix p. 6.

> Respondents who did not benefit economically from wind turbines reported more chronic diseases and health symptoms than those who benefited.... The observed differences between the sub-samples regarding chronic diseases and health symptoms could be due to age effects; respondents who did not benefit economically were older than those who benefited.[224]

Otherwise, through a long and detailed statistical analysis of stress, sleep disturbance, noise, annoyance, and chronic disease, the health symptoms question does not appear again.

The researchers expanded their questioning on mood states by incorporating a screening interview for mental illness used in general medical practice, called the General Health Questionnaire.[225] Despite the name, it is not a health questionnaire, nor is it a measure of psychological stress (which is how the authors use it). The GHQ-12 is a screening tool for mental illness, used to help a physician figure out which of his presenting patients need assessment for psychiatric illness. It was validated (meaning compared against other effective means of diagnosis to see if it identified the right people) for its declared purpose, not as a measure of psychological stress. The authors present it as a "validated instrument" for "measuring 'perceived health,'"[226] then use it in their analysis as a measure of "psychological stress," morphing the question set from one purpose to another to another without justification.[227]

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[224] van den Berg et al. 2008b, p. 49.

[225] Goldberg DP, Hillier VF. 1979. A scaled version of the General Health Questionnaire. Psychol Med 9(1): 139–45. The 28-item GHQ may be found at http://www.gp-training.net/protocol/docs/ghq.doc and the 12-item GHQ (used by van den Berg et al.) at www.webpoll.org/psych/GHQ12.htm.

[226] van den Berg et al. 2008b, p. 20.

[227] van den Berg et al. 2008b, p. 47.

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In the Dutch survey study results, owners of turbines lived the closest to turbines and were able to turn them off if they or their neighbors were bothered by the noise—a key difference between the Netherlands and other countries. These closer respondents tended to be farmers and to benefit economically from the turbines. They were on average younger, healthier, and, as it happens, better educated than the respondents living farther from turbines.

Sleep disturbance, annoyance, and questionnaire measures of stress were correlated with noise levels among people who did not benefit economically from turbines. Annoyance occurred at lower dBA noise levels than for road, rail, or air traffic noise, as in the similar Swedish study. Being awakened from sleep was associated with higher noise levels, and difficulty falling asleep and higher stress scores were associated with annoyance. "Respondents with economic benefits reported almost no annoyance,"[228] though they lived closest to the turbines and experienced the highest modeled noise levels. If turbine owners were turning the turbines off when they were bothered or during sleep, then the modeled noise levels would not have accurately represented real noise levels close to the turbines.

Despite health being inadequately sampled in this study, the authors still draw conclusions that are interpreted popularly as evidence against health effects by wind turbines, in sentences like this one from the authors' summary: "There is no indication that the sound from wind turbines had an effect on respondents' health, except for the interruption of sleep."[229] Though it is downplayed in this sentence, sleep interruption is in fact of great significance to health. The authors are remiss in failing to acknowledge that the study methods do not have the power to detect other health effects.

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[228] van den Berg et al. 2008b, Summary, p. ii.

[229] van den Berg et al. 2008b, Summary, p. ii.

The authors would have more accurately captured the survey's health results had they written, "Sleep disturbance or interruption, an effect of profound importance to health, was correlated with turbine noise levels. Unfortunately, the survey could not effectively address other health questions due to bias introduced at the level of data collection. An important finding is the possibility of biased responses from respondents benefiting economically from turbines, yet it is equally possible that turbine owners are in the habit of turning turbines off at critical times, thus avoiding both annoyance and sleep disturbance."

Recommendations

For physicians practicing near wind turbine installations, I suggest incorporating proximity to turbines into the personal and social history in a neutral and non-suggestive way, especially for the types of symptoms described in this report.

With regard to turbine setback from dwellings: in Table 1B we see that the subjects in the current study lived between 305 m (1000 ft) and 1.5 km (4900 ft or 0.93 mi) from the closest turbine. There were three severely affected families at 930–1000 m (3000–3300 ft) from turbines. This study suggests that communities that allow 305–457 m (1000–1500 ft) setbacks from homes, like those in New York State, may have families who need to move after turbines go into operation.

All turbine ordinances, I believe, should establish mechanisms to ensure that turbine developers will buy out any affected family at the full pre-turbine value of their home, so that people are not trapped between unlivable lives and destitution through home abandonment. By shifting the burden of this expense to turbine developers, I would hope that developers might have a stronger incentive to improve their techniques for noise prediction and

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to accept noise level criteria recommended by such agencies as the World Health Organization and the International Standards Organization,[230] and fortified by the findings of Pedersen (above).

With regard to families already affected, developers and permitting agencies share the responsibility for turbines built too close to homes, and together need to provide the financial means for these families to re-establish their lives at their previous level of health, comfort, and prosperity.

I support the recommendations for noise level criteria and procedures for noise monitoring by George Kamperman and Richard James.[231] A single setback distance may not be both protective and fair in all environments with all types of turbines, but it is clear, from the current study and others, that minimum protective distances need to be more than the 1–1.5 km (3280–4900 ft or 0.62–0.93 mi) at which there were severely affected subjects in this study, more than the 1.6 km (5250 ft or 1 mi) at which there were affected subjects in Dr. Harry's UK study,[232] and, in mountainous terrain, more than the 2–3.5 km (1.24–2.2 mi) at which there were symptomatic subjects in Professor Robyn Phipps's New Zealand study.[233]

Two kilometers, or 1.24 miles, remains the baseline shortest setback from residences (and hospitals, schools, nursing homes, etc.) that communities should consider. In mountainous terrain, 2 miles (3.2 km) is probably a better guideline.

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230 See Kamperman and James 2008b.

231 Kamperman and James 2008b. Presented in shorter form, Kamperman GW, James RR. 2008a. Simple guidelines for siting wind turbines to prevent health risks. Noise-Con, July 28–31, annual conference of the Institute of Noise Control Engineering/USA.

232 Harry 2007.

233 Phipps 2007.

Setbacks may well need to be longer than these minima, as guided by the noise criteria developed by Kamperman and James.

Suggestions for further research

- Epidemiologic studies comparing populations exposed and not exposed to wind turbines with regard to the prevalence of specific symptoms, such as tinnitus and balance complaints. Such studies might be best conducted in European countries that have both national health data systems and significant numbers of wind turbines.
- Case series by neurotologists internationally, who are able to do appropriate objective examinations and testing in addition to clinical history.
- Collaboration between physicians and independent noise engineers to find which specific frequencies and intensities of sound and vibration correlate with subjects' symptoms in real time, and to establish a standard protocol for wind turbine noise sampling that includes these specific frequencies and intensities of sound and vibration.
- Further clinical/laboratory research on the effects of low frequency noise and vibration on the human vestibular system.
- Case control studies by specialist physicians near turbine installations on rarer associated symptoms, such as ocular problems, lower respiratory infections, asthma, persistent middle ear effusions, failure of anticoagulation, loss of diabetes control, exacerbation of arrhythmias, and exacerbation of gastrointestinal conditions.
- Studies of turbine noise and children's learning. Standardized test scores, before and after turbines are built near schools or in a community, might be compared to test scores of similar,

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non-exposed schools and communities across the same years. The current study suggests that both school and home turbine noise exposures would have to be quantified.

Limitations of the study

- The study was done by interview and only limited medical records were available. Physical exam and appropriate testing (such as hearing, balance, and neuropsychological testing) would clarify and provide objective evidence for otologic and neurologic problems. Physical exam and appropriate testing are necessary to assess the rarer associated conditions not included in the core symptoms of Wind Turbine Syndrome.
- Participant memory limitations or distortions. I excluded several families from the analysis because they were unclear about what had happened when, combined with not having spent enough time in a post-exposure situation. I insisted on a post-exposure period to compensate for the difficulty of accurately comparing before-exposure experience to the current situation of exposure.
- Minimization or exaggeration of effects. I felt some subjects may have minimized potentially embarrassing or frightening issues, such as nocturia in men and cognitive difficulties in general. In other families, excluded from the analysis, one spouse was clearly committed to staying in the house and minimized what the other spouse said. I endeavored to protect against exaggeration by including in the study only families who had moved out of their homes or done something else expensive in response to their symptoms, proving their symptom severity in ways other than words. The one exception to this rule was the family of an American physician and nurse, whose professionalism, I felt, was protective.

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- The study was limited to English-speaking subjects. There was only one non-native speaker. He was competent at English and had an English-speaking wife, but there may have been subtleties in his symptoms that he didn't tell me about.
- Small case series sample. For this study, I chose a cluster of the most severely affected and most articulate subjects I could find. It is not a large enough sample to establish a gradient of effects with a gradient of exposure (distance from the turbines). It is not an epidemiologic sample that could establish prevalence of effects within exposure gradients or according to age or pre-existing conditions. Conditions that occurred in one or a few study subjects require case-control studies and cannot be established as part of the syndrome from this study.
- Limited duration of follow-up. For cognitive symptoms improved but not resolved at the post-exposure interview, the time course of resolution is not clear.